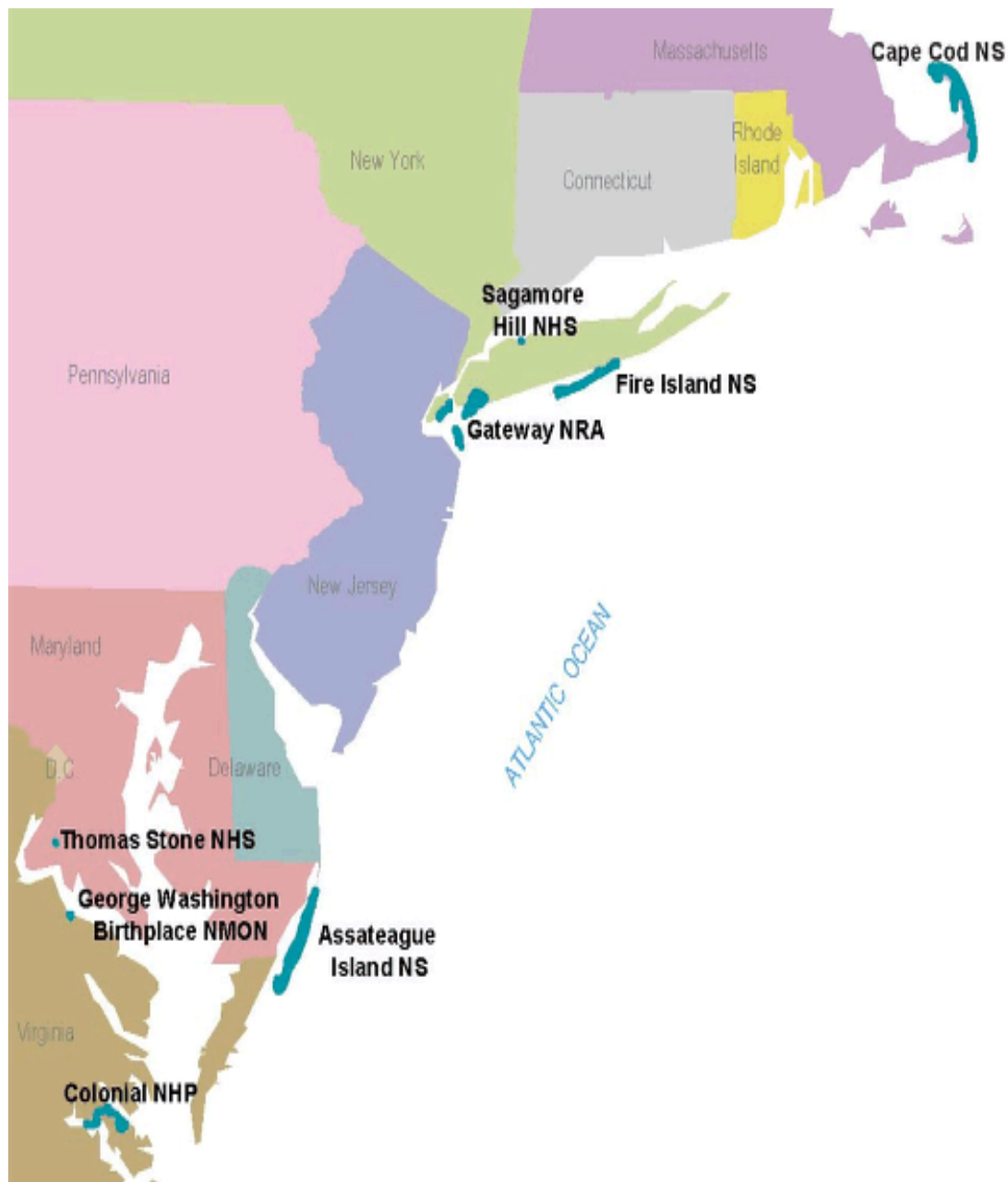


National Park Service  
Northeast Coastal and Barrier Network  
Coastal Geomorphologic Workshops Report

Assateague Island National Seashore, Cape Cod National Seashore,  
Colonial National Historic Park, Fire Island National Seashore,  
Gateway National Recreation Area, George Washington Birthplace National Monument,  
Thomas Stone National Historic Site, Sagamore Hill National Historic Site



September 26, 2003  
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Northeast Coastal and Barrier Network

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## Preface and Dedication

This report represents an edited and reorganized compilation of existing reports, proposals, notes, correspondence, models, diagrams, and various other documents that have addressed the issue of long term monitoring of geomorphologic change in National Park Service coastal units. I would especially like to acknowledge and thank Dr. James Allen, Dr. Charles Roman, and Dr. Nels Barrett for their work that makes up a significant portion of this document. Dr. Allen's writings make up most of the introduction and workshop summary sections, while Dr. Roman and Dr. Barrett composed the Cape Cod Conceptual Model report from which the introduction in the conceptual model section of this report is taken.

In July 2002, the National Park Service (NPS) lost one of its most ardent and passionate advocates for coastal science. Dr. James Allen was the leader in providing Northeast Coastal and Barrier Network Parks with a scientific basis for decision making and management. At the time of his death, Jim was playing a major role in developing a monitoring program that would provide consistency and structure to data collection activities in coastal parks.

Dr. Allen laid the foundation for much of today's emerging National Park Service coastal geomorphologic monitoring program. Whether stretching a tape measure across the beach, riding a GPS equipped ATV along the ocean berm, or jumping into a survey aircraft to take photographs following a major storm event, Jim's passion for measuring and understanding the processes at work in coastal parks made him the agency expert on coastal geomorphology issues. His scientific knowledge and years of experience made him the essential player when the NPS embarked on the establishment of the Northeast Region geomorphologic change program. At each stage of the early planning and scoping process, Jim served as either the workgroup chair or the scientific expert as the agency established the framework for monitoring activity. Major sections of this report including the entire introduction section are taken directly from preliminary text composed by Dr. Allen that have been edited to fit into the context of this document.

Since 1999, as part of the service-wide Natural Resource Challenge initiative, the National Park Service Inventory and Monitoring Program has been developing multi-park networks to monitor significant physical and biological features in National Park Service units. In the agencies Northeast Region, eight parks have been grouped into the Northeast Coastal and Barrier Network. The eight parks are Cape Cod, Fire Island, and Assateague Island National Seashores, Gateway National Recreation Area, Colonial National Historic Park, George Washington Birthplace National Monument, and Sagamore Hill and Thomas Stone National Historic Sites (see cover map and Table 1).

Once the makeup of the network was determined, a number of workshops were held to identify significant resource issues. One of the resource issues identified was geomorphologic change. Scoping and planning workshops were held at the USGS Patuxent River facility (1999), Gateway National Recreation Area (2000), USGS Woods Hole station (2001), and following Dr. Allen's sudden death, in October 2002 at the University of Rhode Island's Coastal Institute. Panels of scientific, technical, and resource management professionals discussed various geomorphologic and related park issues. The discussions led to the development of a conceptual model and the selection of potential features or indicators to be monitored in order to assess changes in park coastal geomorphology. This report represents a summary of those sessions and a listing and organization of their findings.

Park Name	Code	Location	Hectares	Acreage
Assateague Island National Seashore	ASIS	MD, VA	19,200	48,000
Cape Cod National Seashore	CACO	MA	17,442	43,604
Gateway National Recreation Area	GATE	NY, NJ	10,644	26,610
Fire Island National Seashore	FIIS	NY	7,832	19,580
Colonial National Historical Park	COLO	VA	3,740	9,350
George Washington's Birth Place National Monument	GEWA	VA	220	550
Thomas Stone National Historic Site	THST	MD	129	322
Sagamore Hill National Historic Site	SAHI	NY	33	83

Table 1 – Coastal and Barrier Network Parks – General Characteristics

Prior to the creation of the NPS Inventory and Monitoring Networks, Cape Cod National Seashore (CACO) was identified as a coastal prototype park. Many of the activities now being executed and reported by NPS networks had already been accomplished at CACO. In fact, many of the steps listed in the NPS guidance for developing monitoring protocols were based on the prototype park experience. As such, the template used for developing the conceptual model section of this document is a modified version of the Roman and Barrett report - Long Term Ecological Monitoring at Cape Cod National Seashore – A Conceptual Approach (Roman and Barrett, 1999).

The National Park Service coastal monitoring program in many ways owes its existence to the work of Dr. Jim Allen. Replacing the knowledge, experience, and above all, the passion and zest that Dr. Allen brought to Coastal Parks is an impossible task. One of the ways we can honor his legacy is by taking what he tried to teach us and building it into a scientifically sound and rigorous monitoring program. In this way, we can build on the legacy and protect the coastal resources that Jim loved and worked so hard to help us understand.

## Introduction

The problem of land loss/gain at the marine edge is basic among the many issues facing coastal park resource stewards in the Northeast Region of the National Park Service (NPS). Shoreline change is a prime geo-indicator of coastal environmental resource threats within parks. It can be either chronic or episodic, is defined by linear or nonlinear time trends, and displays much spatial variability (Allen and LaBash, 1997; Allen *et al.*, 1999). Change in shoreline position drives allogenic replacement of natural habitats (*c.f.* Roman and Nordstrom, 1988) and shoreline retreat may destroy cultural resources, facilities and other infrastructure where they exist. The primary problem facing park management is manifested as coastal erosion, which results from both natural and anthropogenic sources. However, coastal accretion can also be problematic. Conceptually, coastal erosion is a problem for upland resources because upland resources are not mobile and will be lost. Geomorphologic change is a basic concern because it also drives change in other natural resource areas of interest within the NPS program: water quality in ground and in estuaries, species and habitats of concern, recreational visitor use, and even resource extraction.

Whereas the general policy of the NPS regarding geomorphologic change is to promote and maintain natural processes, many of the northeastern park units were created to commemorate historical sites and events or to provide public recreation. Many resources are at risk due to their

fixed locations in highly dynamic zones of change. Furthermore, in the long-occupied Northeast, the natural landscape has been profoundly altered by human activity. Effects include topographic reconfiguration, ecological modification, and creation of impervious surfaces. The present land cover in the parks is not what it was prior to European colonization. Furthermore, the last century has seen increased human alteration of natural processes. External manipulations beyond the park boundaries also provide problems for managing resources with the goal of preserving natural processes.

Amongst the significant natural resource issues in North Atlantic coastal parks, addressing coastal erosion has been identified as a high priority. Cape Cod NS, Fire Island NS, most of Gateway NRA, and Assateague Island NS are located upon the energetic Atlantic shore. However, Sagamore Hill NHS, Colonial NHP, George Washington Birthplace NM, and Thomas Stone NHS are situated in sheltered, low-energy estuary environments. Nevertheless, they all share the problem of coastal erosion. Much of the resource preservation mandate and contention within NPS units has been focused upon maintaining upland resource stability with little regard to shoreline dynamics. Recently, however, there has been increased interest in coastal geomorphologic change because it is directly related to threats to habitat quality, cultural resources, park facilities, and infrastructure. The agents of change are numerous and operate at different geo-temporal scales. The stressors of beach and dune systems (whether erosion or rapid mobilization) and their complex responses in coastal parks are not well understood. Early identification of changes in past trends, along with some understanding of normal variability, is key to recognition of ecological problems in coastal parks.

The primary geomorphologic variables operating in northeastern coastal parks are sea level rise, wave climatology, and sediment supply. All eastern coastal parks are adversely affected by a relative rise in sea level (roughly 0.2-0.3 m in the last century). Although slow, this is a chronic driving force. Substantial shoreline retreat is also driven by aperiodic storms (tropical cyclones in summer and mid-latitude nor'easters in the winter). Storm effects upon the beach may be ameliorated within a week or two but if the system is degraded, a decade of storm quiescence may be needed for recovery. Furthermore, nearly all coastal locations have a declining sediment supply that contributes to coastal erosion. In addition to the primary variables, there are local conditions that control rates and direction of change. These include the geologic framework, offshore topography, orthogonal fetch limitations, and local sediment sources and sinks. Spatial variability is inherent in shoreline change.

In addition to global, regional, and local natural causes, many cases of coastal erosion are accelerated by human perturbations to the natural system. Specific changes to tides, waves, currents, and availability of sediment have profound morphological and ecosystem feedback. Examples range from stabilized inlets, seawalls, and groins, to hardened shorelines for inland protection, and beach and dune rebuilding with added sand from an external source. While accruing certain general benefits to a variety of coastal users, these projects also affect natural processes. The lag time for natural equilibration is unknown in each case and the duration of impact is often confounded by continued needs for maintenance of existing projects. Habitat and ecosystem responses to such changes are not well understood by ecologists and how long these impacts persist are virtually unknown at the local level. For managers, an understanding of the spatial and temporal patterns of geomorphologic change is basic to optimal management of any coastal park because: 1) the interface of marine and land systems is very dynamic and is driven by multiple forcing mechanisms, 2) it results in alterations to resource patterns and dynamics at habitat and ecosystem level, and 3) it will eventually result in the loss of static resources.

Developing an understanding of these effects would benefit from the establishment of local long term monitoring programs.

## Workshop Summary

Four workgroups were convened between February 1999 and October 2002 to identify key scientific issues, information gaps, and long-term data needs that are relevant within a general coastal resource management framework and specifically to coastal geomorphologic change. The sessions were held respectively at the USGS Patuxent Wildlife Research Center (February 1999), NPS Gateway National Recreation Area (April 2000), USGS Woods Hole Field Center (January 2001), and the University of Rhode Island Coastal Institute (October 2002). The workgroups included scientists, natural resource and technical professionals from federal agencies, universities, and parks involved in research and monitoring of geomorphologic processes.

The Patuxent session (October 1999) identified broad areas of interest to parks for potential monitoring, one of which was geomorphology. The goals of the three subsequent workshops were: to discuss in detail coastal geomorphologic processes and related management issues, to create a conceptual model to guide the development of the monitoring protocols, to identify potential indicators for monitoring including recommendations for frequencies and methods for long term monitoring of park geomorphologic resources.

The Gateway group (April 2000) vigorously discussed a wide range of coastal issues and agreed that one of the fundamental problems facing resource managers is the spatial patterns of loss or gain of land due to geomorphologic change. The best means to understand the process of change, and identify likely causes of problems, is through viewing the sediment budget within the park and within its regional context. Although quantifying the amount of sediment advection is difficult, volumetric imbalances can be identified in sediment source/sink relationships with a reasonable effort at various space and time scales. Current and emerging technologies are readily applicable to the task of solving some data needs, presenting information to managers, and understanding spatial process linkages.

A key summary statement was that NPS managers need to understand, at each park level, “what is the spatial and temporal variation of the frequencies and magnitudes of coastal change?” affecting key resources and the overall integrity of the park(s). Such understanding would identify chronic vs. extreme events, natural vs. human origins, identify local vs. regional patterns of effects, and allow for some aspect of predictability of future problems. The group concluded that the ability to put any storm-driven change into an understood pattern of variability would be very useful to park management. The linkage of shoreline change to other ecosystem resources is critical to the definition and application of strategies for their protection and forecasting of natural evolution.

The group also recognized that although all of the network parks are coastal, there were in reality two distinct types of systems to consider. Incident wave energy was used to separate shoreline dynamics of northeastern U.S. coastal parks into two groups: 1) *open ocean shores* (ocean systems) with high wave energy, mobile (usually sand-sized) sediments, and large length scales of sediment transport, and 2) *fetch-limited shores* (estuary systems) which are defined by smaller spatial scales of sediment transport (e.g. Nordstrom et al., 1996) and different management options (Hardaway and Byrne, 1999). The networks ocean parks contain both types which can

lead to narrowing and eventually to in-place drowning. Despite the energetic differences, both ocean and estuary systems can have high rates of change. Each group possesses different morphology and vegetation, which restrict logistically and technologically the choice and accuracy of available methodologies for assessing trends in geomorphologic change. This distinction between ocean and estuary systems was significant to the Gateway workgroup. It should be noted that while both types were addressed, the emphasis, due to group makeup and interests, level of existing in-park activity, and time limitations was on the ocean systems. It was agreed that the estuary systems would require additional discussion.

A second meeting was held at the USGS Woods Hole facility in Falmouth, MA (January 2001). This four person workgroup was convened to build on the work of the Gateway group by: 1- comparing park needs identified in questionnaires and telephone surveys with indicators identified by the Gateway group, 2- identifying existing park programs that could serve as starting points for monitoring, 3- discussing various methods for data collection including cost estimates and comparisons, 4- identifying non-NPS activity in and around network parks for possible partnering and cost-sharing, and 5- drafting a network monitoring operations plan including estimated costs.

While each of these items was discussed, the one day allotted for the meeting did not allow detailed consideration or in-depth development of plans, methods, and procedures. However, the group was able to make several recommendations for future action. The recommendations included staffing suggestions, data collection activities and frequencies, and estimated cost of selected actions. The major recommended activities included the following:

- Continue existing data collection activities while transitioning to monitoring program
- Create a network position to oversee development of the monitoring program
- Conduct biennial LIDAR surveys of ocean parks (ASIS, CACO, FIIS, GATE)
- Develop contacts at USGS to extract geomorphologic features from LIDAR data
- Develop methods to determine short and long term variability of shorelines
- Perform 2D GPS surveys to determine general trends of shoreline position
- Assemble historic shoreline data sets.

With the sudden death of Dr. Jim Allen in July 2002, the Northeast Coastal and Barrier Network lost a major source of expertise and its primary and most experienced scientific consultant on coastal geomorphology issues. At the time, several critical steps in the protocol development process had yet to be completed. Key unresolved components included the construction of a conceptual model and the continued identification and development of specific monitoring variables. Using a well-established network of scientific and technical cooperators, a new workgroup (see participants, p. 18) met at the University of Rhode Island Coastal Institute (October 2002).

The purpose of the URI workshop was threefold. First, there was an obvious need to create a more team-oriented approach to providing scientific and technical guidance to the network. By expanding the base of its expertise, the network would create a more stable foundation and provide the continuity essential to long-term maintenance of the program. At the same time, an expanded workgroup would increase network access to scientists and other cooperators with considerable experience in and around the individual network parks. Second, the workgroup would discuss coastal processes and construct a conceptual model to guide and justify the

selection of monitoring variables. Third, the group would review existing indicators and recommend additional vital signs for consideration.

The workshop agenda recognized that it had been almost two years since a workgroup had convened and that several participants had not been involved in the previous discussions. Consequently, the first part of the meeting focused on providing background and updates on the purpose and objectives of the monitoring program and work to date on monitoring issues. This formal segment was followed by freewheeling discussion of park needs, geomorphologic processes, and the value and practicality of various monitoring issues and strategies. The final segments of the workshop addressed the creation of the conceptual model and the enumeration of potential vital signs for integration into a long term monitoring program.

Collectively, the workshops produced three major products: 1) a conceptual model of the processes at work in the coastal zone, 2) a list of potential indicators or vital signs for monitoring, and 3) recommendations for prioritization of indicators so that ongoing and readily implementable activity is established and/or continued.

#### The Conceptual Model (Roman and Barrett, 1999)

The conceptual model results from an active dialogue that attempts to objectively identify the major natural processes at work in a park, to identify threats to their normal operation, and to develop methods to reliably and consistently measure and analyze their condition. The model utilizes a three-tiered framework to organize the general ecosystem function. It was developed to assist in identifying important issues confronting these ecosystems, and ultimately, to assist with selection of specific variables to monitor. Each model is a conceptual construct that explains the complex relations among *agents of change*, *associated stressors*, and *ecosystem responses*. (Figure 1). These terms are described briefly below:

*Agents of change* are mechanisms defined as natural processes and events, or human activities. Agents of change can operate within the range of natural variability and acceptable limits of change or they may not. If not, they are the source of stresses.

*Stressors* are the associated problems or products of human activities or natural events (agents) that diminish the quality or integrity of the ecosystem.

*Ecosystem responses* are defined as detectable changes or trends in any measurable function, or process, that are considered indicative of ecosystem quality or integrity. For example, within the ocean beach system, jetty systems are agents of change that can stress the system through disrupting the sediment budget, which can result in an ecosystem response of altered habitats and loss of infrastructure.



## The Coastal Geomorphologic Change Conceptual Model for Beach, Spit, and Dune Habitats

While there are several processes that drive the formation and evolution of Beach/Spit/Dune habitat, a controlling factor in their expression is the shallow geologic framework. Defined here as the geology of the near subsurface, the regional geologic framework exercises considerable influence over the response of nearshore and onshore environments. Knowledge of the geologic framework is critical to understanding short and long-term changes in coastal habitats.

Functioning on top of the geologic framework, the primary processes influencing this habitat include a suite of natural disturbance factors operating at local, regional, and global scales, and anthropogenic activities in the form of land use, and visitor and recreational impacts. Natural disturbances consist of the system driving processes of sea level rise, sediment supply, and wave climate. These components combine to influence both physical and hydrologic features that include the nearshore system of bars, ridges, and shoals, and the movement of water in the form of currents and waves. Collectively, these features and forces direct and control the movement of sediment through the nearshore system.

Ultimately, the presence of Beach/Spit/Dune habitat depends upon the availability of appropriately sized sediments within the system. Finite in supply, sediment availability serves as a limiting factor in the landform's response to the forces of wind and waves. Sediment supply is susceptible to human disturbance and interruptions. When subject to prolonged changes in sediment supply, landforms may react in extreme ways with consequences to the physical environment and associated biota.

Anthropogenic activities also have the potential to alter the processes controlling the habitat, primarily through changes in land use within the coastal zone. Most significant are shoreline stabilization and dredging activities. Each of these practices has the potential to alter existing hydrographic conditions and sediment supply, and influence natural patterns of erosion/deposition, overwash, and inlet formation and migration. When this occurs, core processes are altered and may begin to operate outside the range of natural variation.

Each of the stressors identified in the conceptual model direct change in the habitat. The magnitude and scope of the resultant ecosystem response is complex, highly variable, and can often be cumulative. The most immediate ecosystem response to stressors is a direct change in the physical environment. At the extreme, this includes the loss and/or gain of habitats, such as when coastal erosion creates new aquatic habitat at the expense of terrestrial, or landscape-level reformation as may occur during strong storms. More subtle physical responses also include changes in geochemical and hydrologic conditions, such as alterations in groundwater quality and quantity.

Ecosystem response in the Beach/Spit/Dune Habitat can also be cascading. Stressor-induced changes in the physical environment often elicit secondary responses, such as changes in ecosystem structure or function. Structural responses, such as change in species composition or competitive interactions, generally reflect landscape-level alterations in the quantity and quality of specific habitat attributes. Similarly, functional responses such as changes in productivity or nutrient cycling may occur, often as a product of storm events and the associated reduction in habitat complexity.



# Coastal Geomorphologic Change Model

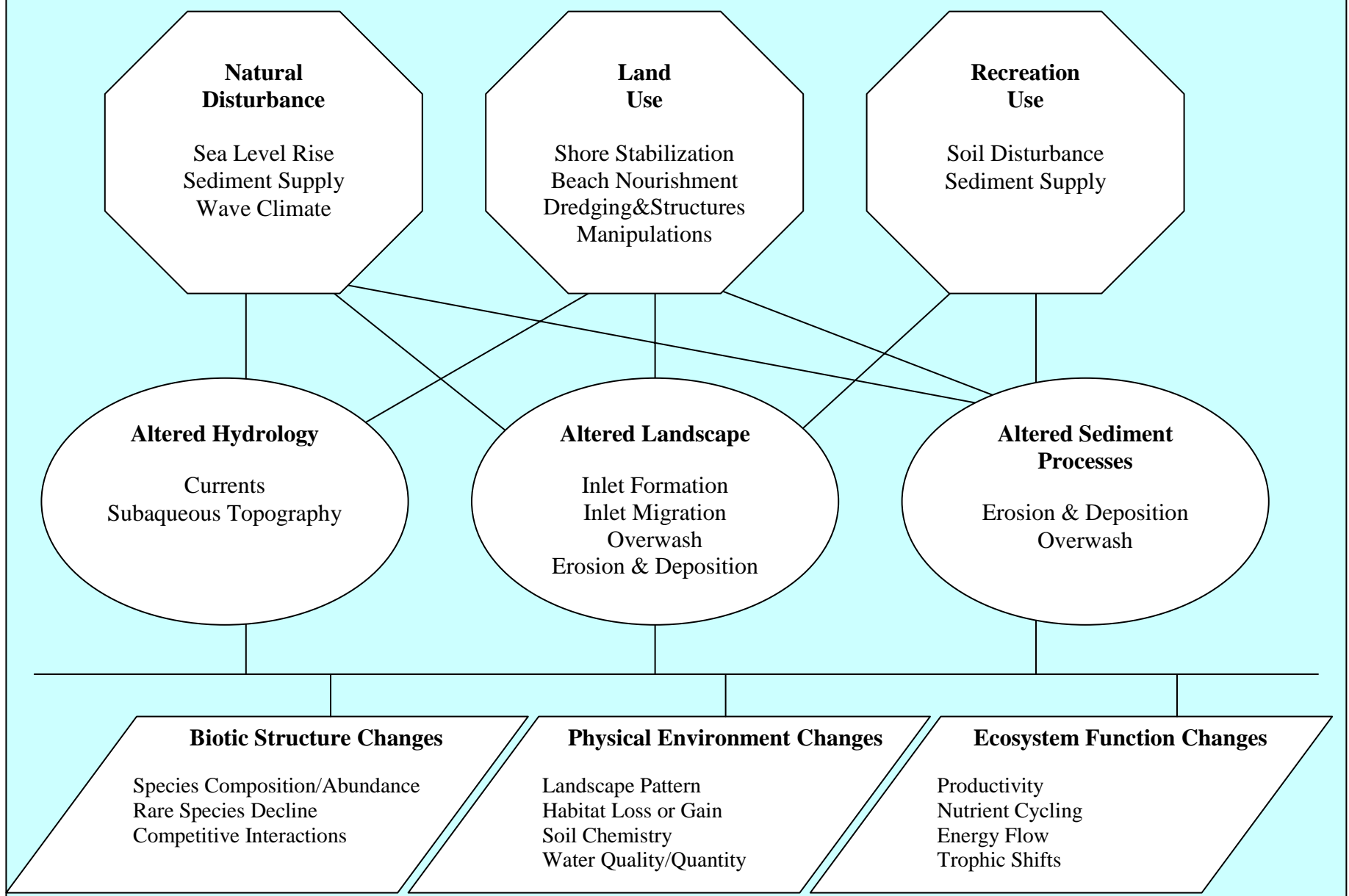


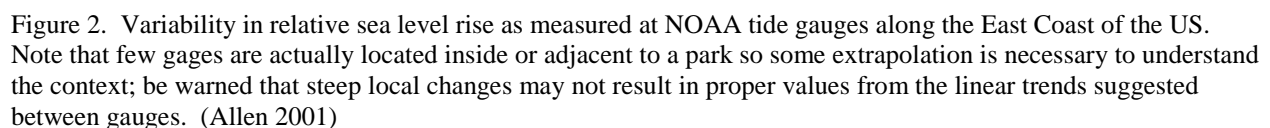
Figure 1. Conceptual Model for Geomorphologic Change

## Identification of Vital Signs

The scientific workshops were convened to address the issue of geomorphologic change. One of the purposes of these meetings was to develop a list of indicators or vital signs. The group started with general feature descriptions, issues, and areas of concern and from there worked toward delineating specific measurable units. The Gateway and Woods Hole workshops focused their attention primarily on ocean shorelines and more generic features while the URI group also addressed the lower energy estuary environments and provided more specific candidate variables for monitoring. At the park level, three basic elements of shoreline change were identified that are reasonably practical to measure, are easily replicated, and thus provide for time series analysis with adequate accuracy and precision, in order to understand the space/time pattern. The general features included three measurable replicable elements of change. In priority order, these variables are *1) an approximation of the general shoreline position, 2) a measure of the more inland interface of the upland edge vs. wave and flood domination, and 3) elevation change data characteristic of the coastal topographic envelope of concern.* The latter, which includes both sub-aerial and sub-aqueous features, combined with items 1 and 2 provides dimensional data on imbalances in mass budgets at specific spatial scales (Allen et al 1999). Anthropogenic manipulations to the system in the form of shore stabilization, dredging, and beach nourishment are considered critical to understanding the process and response of the system. Combining the recommendations of the three workshops generated the following list of potential variable indicators or vital signs:

- geomorphology (temporal/spatial change in coastal features and benthic habitat)
- water lines (high/low/mean tide line), wet/dry sand line~mean high water line
- shoreline erosion/accretion rates
- toe & crest of berm, dune, bluff, cliffs, or bank
- beach topography & profiles
- overwash fans – storm wrack line
- vegetation edge, vegetation zones
- sediment characteristics (volume, thickness, chemistry, mineralogy, source, backscatter)
- sediment transport characteristics
- sedimentation rates
- beach nourishment/dredge disposal sediments, navigation channels,
- dredge disposal areas, beach nourishment source areas, outfalls
- geologic framework
- migrating shoals & bodies
- cores
- nearshore bathymetry
- structures, manipulations, bulkheads
- Dredge channels
- Mosquito ditches
- marsh elevation
- shore type
- habitats
- inlet hazard zones, flood zones, inlet/navigation hazard zones (Shoals, wrecks),
- wave characteristics (height, period, direction)
- longshore and cross-shore current characteristics
- tide range
- relative sea level position
- SAV -submerged aquatic vegetation (types and spatial extent),
- submerged cultural resources

As evidenced by the long list of indicators, the groups agreed that understanding this issue requires an adequate measurement of numerous variables related to the hydrodynamic forcing of sediment transport, morphologic change, and ecosystem response at the level of the individual park unit. Local identification of the rate of relative sea level rise (RSL), tide range, storm surge frequency/magnitude, wave heights, and sediment transport volumes and directions are required to understand the park specific process interaction that is causing geomorphologic change. These are very complex tasks, which are far beyond the capability of the National Park Service to perform alone. However, there are other agencies (federal, state, and local) which have long term coastal research and monitoring mandates that can provide some of the information needed for individual parks. Major coastal research projects are underway at NASA, NOAA, USGS, and USACE and the network is actively developing and strengthening partnerships with all of these agencies. Until these partnerships produce park specific data, regional trends in driving forces must be extrapolated or subjectively interpreted from more general data sources. Figure 2 shows the large regional variability in relative sea level rise along the eastern seaboard due to regional subsidence, local subsidence from fluid withdrawal, and local compaction of barrier islands. Large-scale processes such as barrier breaching and overwash regimes must be clearly linked with estuarine circulation patterns and ecosystem requirements.



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In order to address the various protocols and fledgling partnerships, and to allow time to develop complex, technically challenging methods, a phased approach to implementation is recommended. The general framework for timely implementation of specific monitoring activity is already established at all four ocean parks and is under development in the estuary parks. Some of the data collection activities recommended by the workgroups are already operating in many network parks.

The workgroup discussions, and the conceptual model and table illustrate that the coastal zone is a highly complex environment with multiple related processes operating simultaneously. The list of desirable variables for monitoring numbers in the dozens and ranges from activity that is extant, executable, and affordable at the park level to highly technical, research oriented, and expensive tasks that will require considerable multi agency coordination.

Mirroring the complexity of process, the coastal zone is also an area of extensive research and related scientific activity. Information gleaned at these workshops and through other interagency activity indicates that several national coastal mapping efforts are underway. The USGS, NASA, NOAA, and USACE each have their own national coastal research or mapping programs and the NPS alone has two independent cooperative coastal programs (Coastal I&M Networks and Coastal Geologic Resource Inventory). The presence of multiple agencies with related but not identical coastal research issues and data needs creates an excellent opportunity for the National Park Service. Using the models developed over several years at various parks, the park service should use its limited but significant resources to steer research activity into parks and coordinate the activity so that both the research needs of the scientific community and the information needs of the NPS are addressed.

Table 2a - List of Terrestrial Vital Signs and Measurements

<b>Vital Sign</b>	<b>Measurement</b>	<b>Scientific Justification Conceptual Model Fit Comments</b>	<b>Monitoring Methods</b>	<b>Feasibility</b>	<b>Information Content</b>
<b>Terrestrial Features</b>					
Shoreline position	Shoreline Position	Expression of altered landscape pattern and habitat loss or gain. Compatible with existing long-term data Easily used by park management	2D and 3D GPS Aerial Photography LIDAR	high	high
Topography	Landscape Pattern	Expression of altered landscape pattern and habitat loss or gain.	LIDAR 3D RTK GPS 3D Survey	high	high
Topography	Dune, cliff, bank, bluff features	Expression of altered landscape pattern and habitat loss or gain. Linked to changes in physical environment and ecosystem structure	LIDAR Aerial Photography	medium	high
Topography	Edge of vegetation	Expression of altered landscape pattern and habitat loss or gain. Less variable indicator of overall morphologic change.	Aerial Photography 2D GPS Survey	high	high
Topography	Overwash fans/flood plains	Indicator of areas of active change and potential threat to habitat Expression of altered landscape pattern and habitat loss or gain. Identified as stressor in model	Aerial Photography LIDAR 2D GPS Survey	medium	high
Manipulations	Locations of anthropogenic structures and disturbance	Agent of change driving all stressors Sediment transport and altered hydrographic impact	Aerial Photography 2D and 3D GPS Survey	medium	high
Sediment	Sediment size	Indicator of sediment supply	Sediment Samples	medium	medium
Geology	Geologic framework	Linked to overall geologic integrity/stability Underpinning of AOC hydrography, sediment supply, natural disturbance Structure on which drivers and stressors operate Inventory item – does not require frequent measurement	Acoustic Survey Seismic Survey Core Samples	low	high
Land Use	Shore type	Less variable indicator of overall morphologic change Landscape pattern indicator	Aerial Photography 2D and 3D GPS Survey	medium	medium

Table 2b – List of Marine Vital Signs and Measurements

<b>Vital Sign</b>	<b>Measurement</b>	<b>Scientific Justification Conceptual Model Fit Comments</b>	<b>Monitoring Methods</b>	<b>Feasibility</b>	<b>Info Content</b>
<b>Marine Features</b>					
Bathymetry	Depths	Influence on waves, currents, and sediment Linked to hydrography, sediment supply, and natural disturbance	Acoustic Survey Bathymetric LIDAR Sled survey	low	medium
Bathymetry	Migrating shoals & bodies	Influence on waves, currents, and sediment Linked to hydrography, sediment supply, and natural disturbance	Acoustic Survey Bathymetric LIDAR	low	high
Geology	Geologic framework	Linked to overall geologic integrity/stability Underpinning of AOC hydrography, sediment supply, natural disturbance	Acoustic Survey Seismic Survey Core Samples	low	high
Sediment	Sediment Characteristics	Indicator of sediment supply Stressor factor	Offshore samples	low	medium
Hydrology	Wave and current characteristics	Hydrologic driver of change Driver of erosion/deposition, overwash, inlet formation/migration	Local Gauge Regional Gauge	medium	high
Hydrology	Tide range	Indicator of variability Driver of erosion/deposition, overwash, inlet formation/migration	Local Tide Gauge Regional Tide Gauge	medium	medium
Hydrology	Relative sea level position	Along with weather the primary natural driver of shoreline change. Driver of erosion/deposition, overwash, altered hydrography, inlet formation and migration	Water Level Gauge	medium	high



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